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New altitudinal record for *Brachycephalus actaeus* Monteiro, Condez, Garcia, Comitti, Amaral & Haddad, 2018 (Anura, Brachycephalidae), with comments on its habitats of occurrence

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Abstract

Brachycephalus actaeus Monteiro, Condez, Garcia, Comitti, Amaral & Haddad, 2018 is a recently described member of the *B. pernix* species group from northeastern Santa Catarina, southern Brazil, where it has been recorded from six localities at altitudes of 20–220 m. At the time of its description, this species was believed to be associated with lowlands, a unique trait for members of the *B. pernix* group. Here, we extend altitudinal distribution of *B. actaeus* to 530 m elevation and determine that the species occupies only montane forests.

Keywords

Brachycephalus pernix group, Floresta Ombrófila Densa das Terras Baixas, lowlands, montane forest, sandy soil.

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Introduction

Brachycephalus Fitzinger, 1826 includes 36 species of small, diurnal anurans endemic to the Atlantic Forest biome of Brazil. Interestingly, 30 of those species were described in the last 20 years. These anurans do not exceed 2.5 cm in body length (snout–vent) and have reduced number and size of digits (e.g. Yeh 2007). Some species are brightly colored with neurotoxins in their skin (Schwartz et al. 2007). In general, *Brachycephalus* is characterized by small geographical distributions, with several species being micro-endemic to a single or a few adjacent mountaintops of the Atlantic Forest (Bornschein et al. 2016a).

Environmental niche modeling grouped *Brachycephalus* into three species clusters based on their climatic niches (Pie et al. 2013). Those clusters were then shown to match closely three phenetic groups of species (Ribeiro et al. 2015), which respond differently to altitude (Bornschein et al. 2016a). For instance, species from the *B. ephippium* and *B. pernix* groups (Ribeiro et al. 2015) are closely associated with higher altitudes (Bornschein et al. 2016a). Although there are some populations of these groups at relatively lower altitudes, they tend to be considered as montane groups because they only occur under specific microclimate conditions typical of montane habitats (Bornschein et al. 2016a). On the

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other hand, the *B. didactylus* group (Ribeiro et al. 2015) includes species that are variable in altitudinal distribution, occurring from sea level up to 1,110 m above sea level (a.s.l.) (Bornschein et al. 2016a).

High-altitude dependence of the montane groups of *Brachycephalus* has been associated with speciation by isolation (Bornschein et al. 2016a; Firkowski et al. 2016). An increasing warmer and wetter climate, particularly over the past 5 My, led to a shift in the distribution of the cold-adapted forest types to higher altitudes, favoring the isolation and speciation of montane *Brachycephalus* populations in sky islands (Bornschein et al. 2016a; Firkowski et al. 2016; Pie et al. 2018a). Recently, an additional species of the montane *B. pernix* group from northern Santa Catarina, *B. actaeus* Monteiro, Condez, Garcia, Comitti, Amaral & Haddad, 2018, has been described and associated with lowlands (Monteiro et al. 2018). In this work, we present new altitudinal records for *B. actaeus* and discuss its occurrence habitats.

Methods

We actively searched for individuals of *B. actaeus*, guided by their calls. These searches were made during the day, given that *Brachycephalus* are usually the only amphibians that call continuously during this period. Upon detecting their calls, we approached them to make recordings and to try to find specimens by removing the leaf litter under which they shelter. We collected specimens, which were deposited in the Museu de História Natural Capão da Imbuia, Curitiba, Paraná. We classified the habitats of collections according to the Brazilian Vegetation Classification System (Veloso et al. 1991). Prior to the description of *B. actaeus*, we visited localities cited in Monteiro et al. (2018) and classified the habitats according the classification of Veloso et al. (1991).

The datum used for recording geographical coordinates was WGS84. Collections were made under a permit issued by ICMBio/SISBIO (#55918-1).

Results

New records. Brazil: Santa Catarina, municipality of Itapoá: Serra da Tiririca (26°07′42″S, 048°44′32″W; 170–530 m a.s.l.; Fig. 1), 11 January 2017, coll. by Marcos R. Bornschein, Marcio R. Pie, Luiz F. Ribeiro, André E. Confetti, and Mário J. Nadaline (10 unsexed specimens; MHNCI 10832, 10833, 10834, 11024, 11025, 11026, 11027, 11028, 11029, 11030; Fig. 2).

We recorded *Brachycephalus actaeus* in a montane dense ombrophylous forest (Floresta Ombrófila Densa Montana) at Serra da Tiririca (Table 1). We also recorded the species in a submontane dense ombrophylous forest (Floresta Ombrófila Densa Submontana) at Braço do Norte (26°07′30″S, 048°43′47″W; 210–220 m a.s.l.), municipality of Itapoá, Santa Catarina, on 11 January 2017, and in a submontane dense ombrophylous forest at Serra da Palha (26°17′50″S, 048°40′27″W; 60–90 m a.s.l.; Table 1), Laranjeiras, Ilha de São Francisco, municipality of São Francisco do Sul, Santa Catarina, on 18 February 2017, where we were not successful in collecting specimens, despite hearing their calls.

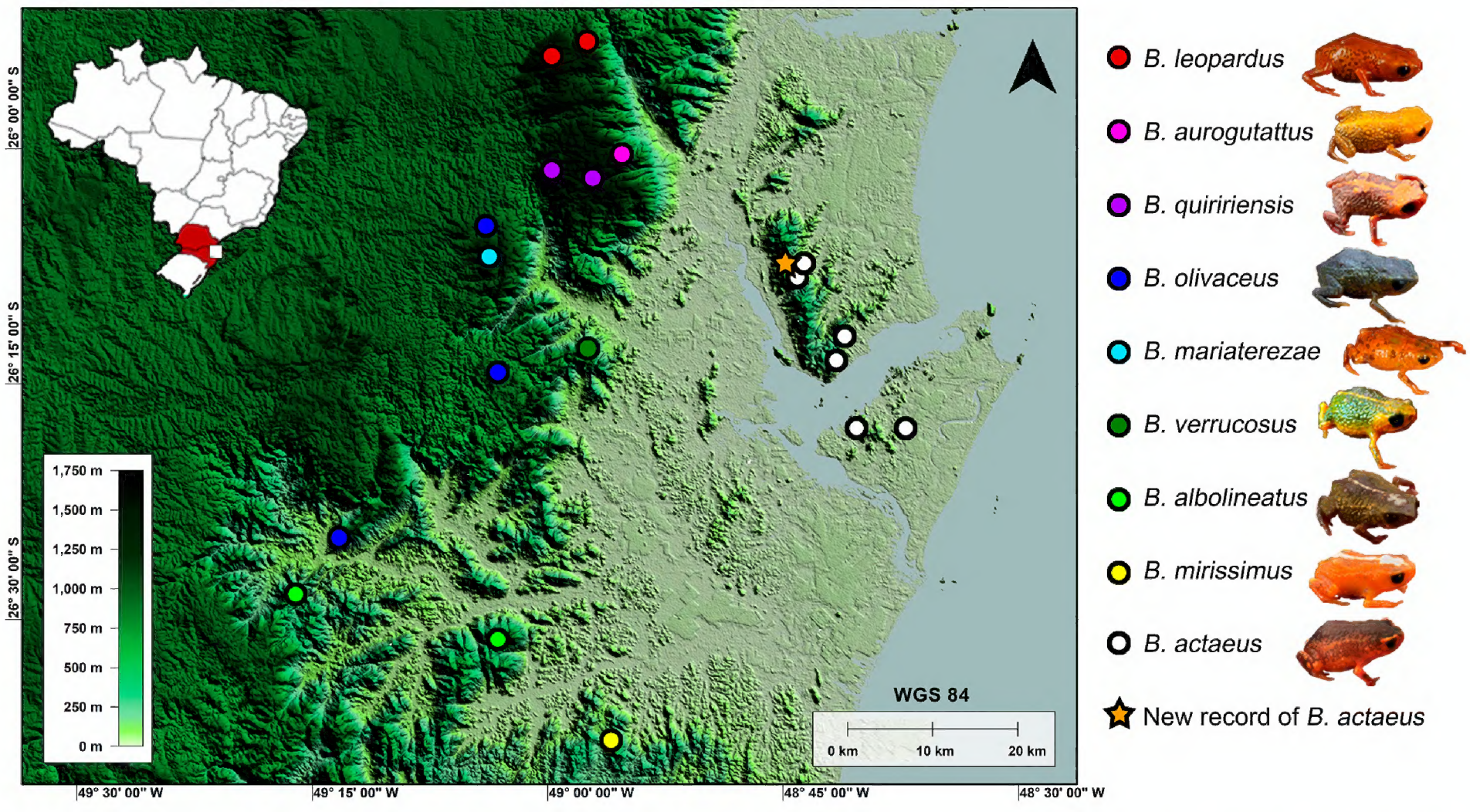

Figure 1. Geographic distribution of *Brachycephalus actaeus*, highlighting the new record at 530 m above sea level (orange star) and previous records (black and white dots) of the literature (up to 220 m above sea level; Monteiro et al. 2018), Santa Catarina, southern Brazil. All *Brachycephalus* records are also presented within a 50 km radius of records of *B. actaeus* (based on Bornschein et al. 2016a; Pie et al. 2018b; Teixeira et al. 2018).

Table 1. Altitudinal (m a.s.l.; rounded to the nearest five) distribution range and habitat of occurrence of *Brachycephalus* spp. In the source column, we only cited the sources that update Bornschein et al. (2016a).

Species	Altitudinal range	Altitudinal amplitude	Source	Habitat[1]								
				Arboreal vegetation[2]							Grassland[3]	
				DAM	DM	DSM	DTB	OM	ES	Sec	RV	E
B. didactylus group	0–1,205	1,205		X	X	X	X	X		X		
B. didactylus	35–1,110	1,075										
B. hermogenesi	0–1,090	1,090	This study		X	X	X			X		
B. pulex	800–930	130			X							
B. sulfuratus	40–1,205	1,165	This study	X	X	X		X		X		
B. ephippium group	200–1,900	1,700			X				X	X		
B. alipioi	1,070–1,100	30			X							
B. bufonoides	?	?										
B. crispus	800–1,190	390	This study		X							
B. darkside	1,265–1,500	235	Guimarães et al. 2017						X			
B. ephippium	200–1,250	1,050										
B. garbeanus	1,130–1,900	770										
B. guarani	500–900	400										
B. margaritatus	600–980	380										
B. nodoterga	700–900	200	This study		X							
B. pitanga	900–1,140	240			X					X		
B. toby	750–1,060	310	This study		X							
B. vertebralis	760–1,110	350	This study		X							
B. pernix group	20–1,770	1,760		X	X	X				X	X	X
B. actaeus	20–530	510	This study, Monteiro et al. 2018		X	X						
B. albolineatus	500–835	335	Bornschein et al. 2016b, Teixeira et al. 2018		X							
B. auroguttatus	1,070–1,100	30		X								
B. boticario	685–795	110	This study		X							
B. brunneus	1,095–1,770	675	This study	X	X					X		
B. coloratus	1,145–1,230	85	Ribeiro et al. 2017	X	X							
B. curupira	1,095–1,320	225	This study, Ribeiro et al. 2017, Pie et al. 2018a	X	X					X		
B. ferruginus	965–1,470	505		X								
B. fuscolineatus	525–790	265	Bornschein et al. 2019		X							
B. izecksohni	980–1,340	360		X	X						X	
B. leopardus	1,340–1,645	305	This study	X								X
B. mariaeterezae	1,265–1,270	5		X								
B. mirissimus	470–540	70	Pie et al. 2018b		X							
B. olivaceus	650–985	335	This study		X							
B. pernix	1,135–1,405	270		X								
B. pombali	845–1,300	455		X	X							
B. quiririensis	1,240–1,380	140		X								
B. tridactylus	805–910	105			X							
B. verrucosus	455–945	490			X							
Incertae sedis												
B. atelopoide	?	?										

[1]Habitat classified according Veloso et al. (1991) by personal observation of the authors of the habitat of the species or if classified in the literature (Guimarães et al. 2017).
[2]Arboreal vegetation: DAM = Floresta Ombrófila Densa Altomontana (highland dense ombrophilous forest); DM = Floresta Ombrófila Densa Montana (montane dense ombrophylous forest); DSM = Floresta Ombrófila Densa Submontana (submontane dense ombrophilous forest); DTB = Floresta Ombrófila Densa das Terras Baixas (lowland dense ombrophylous forest); OM = Floresta Ombrófila Mista Montana (mixed montane ombrophylous forest); ES = Floresta Estacional Semidecidual Montana (montane semideciduous seasonal forest); Sec = secondary vegetation not yet regenerated into a forest stage.
[3]Grassland: RV = Refúgio Vegetacional (or *campos de altitude*); E = Estepe Gramíneo Lenhosa (or *campos de altitude*).

Identification. Our specimens collected at Serra da Tiririca closely resemble the paratype of *B. actaeus* represented in figure 6A of Monteiro et al. (2018). The specimens unambiguously match the *B. pernix* group by the presence of a bufoniform body shape and the linea masculina (Pie et al. 2018b). Within this group, *B. actaeus* can be easily distinguished from *B. ferruginus* Alves, Ribeiro, Haddad & Reis, 2006, *B. izecksohni* Ribeiro, Alves, Haddad & Reis, 2005, *B. leopardus* Ribeiro, Firkowski & Pie, 2015, *B. mariaeterezae* Bornschein, Morato, Firkowski, Ribeiro and Pie, 2015, *B. mirissimus* Pie, Ribeiro, Confetti, Nadaline & Bornschein, 2018, *B. pombali* Alves, Ribeiro, Haddad & Reis, 2006, and *B. tridactylus* Garey, Lima, Hartmann & Haddad, 2012 in having dorsal parts predominantly brownish instead of entirely yellow or orange dorsal parts, at

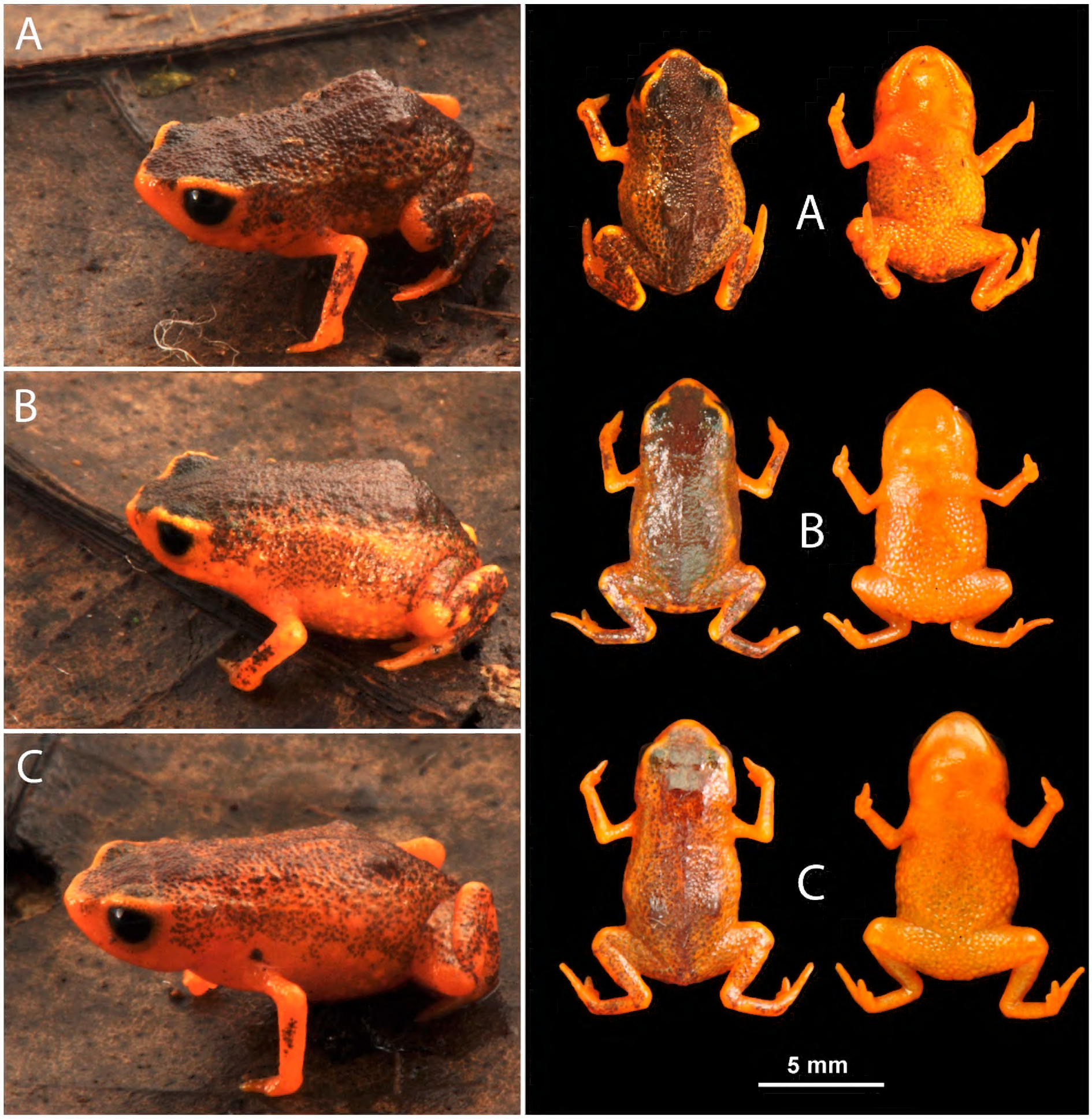

Figure 2. Representative variation in coloration of *Brachycephalus actaeus* from Serra da Tiririca, municipality of Itapoá, Santa Catarina, southern Brazil. All adults are alive and shown in lateral, dorsal, and ventral view. **A.** MHNCI 10833. **B.** MHNCI 10832. **C.** MHNCI 10834. Abbreviation: MHNCI = Museu de História Natural Capão da Imbuia, Curitiba, Paraná.

least with a narrow blue (*B. mariaeterezae*), white stripe (*B. mirissimus*), or orange dots (*B. ferruginus*). *Brachycephalus auroguttatus* Ribeiro, Firkowski, Bornschein & Pie, 2015, *B. boticario* Pie, Bornschein, Firkowski, Belmonte-Lopes & Ribeiro, 2015, *B. pernix* Pombal, Wistuba & Bornschein, 1998, *B. quiririensis* Pie & Ribeiro, 2015, and *B. verrucosus* Ribeiro, Firkowski, Bornschein & Pie, 2015 have a yellow stripe on the middle of their dorsum instead of the entirely brownish dorsum of *B. actaeus*. *Brachycephalus fuscolineatus* Pie, Bornschein, Firkowski, Belmonte-Lopes & Ribeiro, 2015 has a brown stripe on the middle of the dorsum and a vivid orange elsewhere, whereas *B. actaeus* has a more extensive brown area in the middle of the dorsum, surrounded by dark orange washed with brown. *Brachycephalus albolineatus* Bornschein, Ribeiro, Blackburn, Stanley & Pie, 2016 and *B. olivaceus* Bornschein, Morato, Firkowski, Ribeiro & Pie, 2015 have the dorsal and lateral parts of the body predominantly green instead of brown dorsal parts with orange washed brown lateral parts of the body of *B. actaeus*. *Brachycephalus brunneus* Ribeiro, Alves, Haddad & Reis, 2005 and *B. curupira* Ribeiro, Blackburn, Stanley, Pie & Bornschein, 2017 have ventral parts predominantly brown instead of predominantly orange. Finally, *B. coloratus* Ribeiro, Blackburn, Stanley, Pie & Bornschein, 2017 has a reddish dorsum and green lateral parts of the body, clearly contrasting with a brown dorsum and orange washed brown lateral parts of *B. actaeus*.

In having a rough dorsum, *B. actaeus* is also distinct from 10 other species of the *B. pernix* group, which present a smooth dorsum, namely: *B. albolineatus*, *B. brunneus*, *B. coloratus*, *B. curupira*, *B. ferruginus*, *B. izecksohni*, *B. leopardus*, *B. pernix*, *B. pombali*, and *B. tridactylus*.

These colorations and skin texture of the dorsum were assessed from material examined by us over the past years. Lists of vouchers can be followed in recent publications (Ribeiro et al. 2015, 2017; Bornschein et al. 2016b, Pie et al. 2018b; Teixeira et al. 2018). These sources of species descriptions were also used by Monteiro et al. (2018) in the diagnosis that they proposed of *B. actaeus*. Thus, the comparisons that these authors and we provide, based on the two sources of morphological characters that we use, are totally congruent.

Discussion

We recorded *Brachycephalus actaeus* at three localities, two of which (Braço do Norte and Serra da Palha) were already known (Monteiro et al. 2018). For the new locality (Serra da Tiririca) we report an extension of the altitudinal distribution of *B. actaeus* from 220 m a.s.l. (Monteiro et al. 2018) to 530 m a.s.l. This species now has an altitudinal range of distribution of 510 m, a narrower altitudinal distribution than recorded for three species of the *B. didactylus* group (>1,000 m; Table 1), two species of the *B. ephippium* group (Table 1), and one species of the *B. pernix* group (*B. brunneus*, with 695 m of altitudinal distribution; Table 1). This altitudinal distribution of 510 m is similar to that recorded for *B. ferruginus* (505 m), *B. verrucosus* (490 m), and *B. pombali* (455 m;), all within the *B. pernix* species group, and is wider than those recorded from remaining *Brachycephalus* species (Table 1).

Monteiro et al. (2018) associated *B. actaeus* with "lowlands" (no terminological basis was offered). This association may have been based on the lower altitude (20 m) that Monteiro et al. recorded the species at Serra da Palha. According to Veloso et al. (1991), the forest type that occurs in the lowlands is lowland dense ombrophylous forest (Floresta Ombrófila Densa das Terras Baixas). This is the forest type of Pleistocene plains and typically grows over sandy soils between 5–30 m a.s.l. in meridional latitudes (24–32°S; Veloso et al. 1991). Although it is possible that lowlands forests occur at 20 m a.s.l. in the latitude of occurrence of *B. actaeus* (Veloso et al. 1991), that is not the case at Serra da Palha, given that at 15 m a.s.l. and above we found only montane forests (submontane dense ombrophilous forest; MRB pers. obs.) at this locality.

Within its altitudinal range, *B. actaeus* occurs in two types of montane forest (montane dense ombrophylous forest and submontane dense ombrophylous forest; Table 1). Five other species of the *B. pernix* group also occur in two types of montane forest (highland dense ombrophylous forest and montane dense ombrophylous forest; Table 1). However, *B. actaeus* is the only species of this group that occurs in the submontane dense ombrophylous forest. In the lowland dense ombrophylous forest, there are records of *B. hermogenesi* (Giaretta & Sawaya, 1998) (Giaretta and Sawaya 1998; Table 1), from the *B. didactylus* group.

Serra da Palha is situated on the island Ilha de São Francisco, where the sandy soil is particularly young, having an age of approximately 5,000 years (Zular et al. 2013). If a species of the montane groups of *Brachycephalus* is indeed present at lowland forests in young terrains of a few thousands of years, that would be of great relevance to understanding the evolution of spatial occupation and dispersal of the genus. However, according to the present data, no evidence has emerged indicating the presence of species from the *B. pernix* species group in lowland forest types (Table 1).

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Authors' Contributions

MRB, LFR, LT, and MRP made field works; MRB, LFR, LT, and MRP collected the data; MRB and LT wrote the text and made the analysis; LFR took the photographs.

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